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# SURFACE RESPONSE STUDIES OF COBALT BASED CLAD DEVELOPED THROUGH MICROWAVE ENERGY ON MARTENSITIC STAINLESS STEEL

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***ABSTRACT***

***Slurry erosion is always a major problem in the turbine of hydroelectric power plant. It mainly occurs due to the presence of sand particles in the water which flows through the hydraulic turbine leads to erosion of the blade surface. In order to overcome this problem some corrective measure need to be taken. It is very much essential to manufacture the turbine with steels which resist slurry erosion to a greater extent. Stainless steels (AISI-420) are serving as an excellent purpose in this concept and proved to be one of the most significant materials in this case. The surface characteristics of engineering components have a major effect on the life and serviceability of a component, thus it cannot be ignored in design. Surface engineering can assist to deal with these conditions to pick up the service life and also to improve the overall performance of the components. Therefore, the development of surface quality and its characterization plays a major role in surface engineering. However, cladding on the stainless steel material proves the most effective surface modification method in enhancing the slurry erosion resistance. The cobalt based clad exhibits excellent wear resistance. Accordingly, in the present work cobalt based clads were developed on martensitic stainless steel (AISI-420) respectively through microwave irradiation. A domestic microwave oven was used to develop cobalt based clad on the substrate (AISI-420). Wear behavior of developed clad surface was evaluated as per Taguchi orthogonal array. It is also observed from the regression model that the interactions between the variables had a very least effect on the erosive wear rate of the developed clad surface. As observed from the response of surface methodology, maximum erosion was observed at lower impact angle and higher rotational speed, where the minimum wear rate took place at higher impact angle with lesser speed.***

***KEYWORDS: Slurry, Erosion, Microwave Oven, Martensitic Stainless Steel & Surface Response***

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## 1. INTRODUCTION

Surface engineering is the subsection of material science which focuses on the surface of the material. In general, the surface of engineering components consequently fails more frequently, when the surface cannot withstand the subjective environment or the external forces to which it is subjected. The selection of surface material with all aspects like magnetic and electrical properties, wear and corrosion resistance plays very important to its functionality. Improved ecological sustainability and condensed entire life cycle expenses are significant drivers in industry today. Several engineering machines / prime movers fail mainly because of corrosion and wear in destructive environments. The hydro-electric and gas turbine plant components are frequently subjected to such harsh working environments and leads to fail repeatedly [1,2]. Designing of such machine parts for extensive life is

generally concentrates on design of material in bulk form with corrosion and wear resistance, and modification of functional surface to work adequately in the harsh working environment. Oxidation, corrosion and wear are primarily surface related phenomena, hence, designing new material by alternating the bulk of component is not a practical response [3].

The working properties of engineering equipment can be improved by appropriate modifications of exposed surface through various techniques like carburizing, thermal spraying, various cladding techniques, etc. Surface engineering is also an appropriate tool for facilitating best materials range and inventive product design. Surface engineering covers a broad series of processes. At end level, ion implantation, aluminizing and nitriding affect the properties, chemistry of substrate thin surface layer, through modifying present surface. The processing parameters and compositions are the most important factors for coating application and its performance characteristics [4]. Generally, the range of coatings from pure ceramics to pure organic materials provides very different properties in character, but offering significant benefits to the component. Cladding technique is broadly used in surface engineering method to develop surface of the substrate of preferred properties by effective melting of the clad material, partial melting of the surface of the target substrate. The treatments like plating or coating deposit to form hard surface layers.

Slurry erosion is a serious problem with turbine components in hydroelectric power plants and also it is one of the major reasons for serious economic losses. There are various methods available to avoid the slurry erosion. However, surface modification of the turbine component plays a very important role. This chapter highlights an over view of the research work carried out in the area of surface modification through various techniques. The gaps observed in research literatures have been highlighted. The objective and scope of the work is presented. Surface engineering is preferred to a wide diversity of techniques that are designed to develop surface quality of engineering components exposed to severe environment. The processes of surface modification techniques are related to improving the resistance to corrosion and other modes of surface-wear. There are many commercial techniques available to enhance the quality of surface of the components exposed to microwave environment, which includes Tungsten Inert Gas surfacing (TIG), laser cladding and High Velocity Oxy-Fuel (HVOF) or thermal spraying and very recently microwave cladding. Surface engineering gives very good solutions to engineering components in terms of life cycle cost, quality and performance. The surface characteristics have major effect on performance and reliability of component; therefore, it cannot be ignored in component design. The environments of engineering are severe. They are usually complex, combining load with physical and chemical deprivation to the component surface. Surface engineering can deal with these conditions to pick up the service life and also to improve the overall performance of the components. Therefore, the development of surface quality and its characterization plays a very important role in surface engineering.

Cladding is generally used surface engineering method to extend an overlay of proper materials on substrates of preferred properties by partial melting of substrate, full melting of the clad material. Majority of the existing techniques are growing fast in terms of technological developments and in academic research. The surface degradation is a common problem in several engineering industries, which is mainly due to wear and corrosion. The component failure may lead to regular collapse of the method, which may further lead to excess economical load on the industries. Hence, to reduce these types of problems, various surface modification methods are in practice. Recently, microwave heating technique in the ground of clad development has been explored by many researchers [5]. Cladding through microwave energy was observed to be most economical, less time and energy consumable process as compared to other cladding techniques.

It is also observed that the microstructure of the clad developed through microwave energy possesses minor defects like solidification cracks and porosity which leads to enhanced mechanical properties of the target surface.

It is observed from the available literature that researchers have done a good amount of work in the area of processing of ceramics through microwaves. However, not much work reported in the processing of metals, that too in surface engineering. Very few researchers have reported the successful development of nickel and tungsten based cladding on the austenitic stainless steel substrate through microwave energy. There are very few reports available in slurry erosive wear studies of microwave clad developed on austenitic and martensitic stainless steel. Hence, there is a lot of scope in this area of research.

## 2. EXPERIMENTAL DETAILS

The interaction of microwaves with bulk metal is a greater challenge in the domestic microwave oven. Hence, many numbers of experiments were carried out to develop sound clad on the desired surface. The current chapter explores the details about the substrate material and clad powder. The depth of information about microwave cladding process and various characterization techniques used are described in this chapter. The information about the slurry erosive wear studies through design of experiment technique and selection about process parameters are highlighted. The received stainless steel plates were machined to a size of $25\times65\times6$ mm$^3$. Initially, the machined substrates were polished with SiC emery paper to eliminate the initial surface roughness and cleaned with acetone to remove possible dust particles present on the surface of the substrate. The clad powder was placed manually on the desire substrate with an approximate thickness of 1 mm. Further, approximately 1mm thick graphite sheet was placed on the preplaced powder of the substrate to avoid any possible concentration between clad powder and susceptor. Later, charcoal powder (susceptor) was spread on the graphite sheet to enrich the microwave heating effect between clad powder and substrate. Here, the graphite sheet acts as a separator. Finally, the whole arrangement was kept inside the microwave oven. The domestic microwave oven (Make: LG, Model: ML-3483FRR Solar Dom, frequency 2.45 GHz with 900 W power capacity) was used to develop cobalt based clads on martensitic stainless steel substrates respectively.

Cobalt based alloy is widely used as a cladding material because of its high erosion resistant ability. Martensitic stainless steel (AISI-420) was used as a substrate and rectangular plate with thickness of 6 mm was received. The clad powder was manually placed on the substrate (AISI-420) with an approximate thickness of 1 mm. Alumina casket (box shape) was used during experimentation in order to avoid direct exposure of metals to microwave and to make maximum interaction of microwaves with metals at the later stage. Finally, the microwave clads were developed with microwave exposure time of 35 minutes. In order to know the actual time for cladding, various experimental trials were carried out by altering the microwave exposure time. The developed cobalt based microwave clad samples are shown in Fig.

**Figure 1: View of Cobalt based Clad on Martensitic AISI-420 Steel**

In order to analyze the developed clad, various characterization techniques were used. There is an immense array of scientific tools and techniques existing to the material engineers that enables the characterization. Scientific techniques used to characterize the developed clads are illustrated in this section.

## 3. RESULTS & DISCUSSIONS

Slurry erosion is a progressive loss of the material from a target surface by the act of the slurry flowing or sliding on the exposed surface. The slurry erosive is a function of the character of slurry components and the fluid. Slurry erosion is common in oil well fluid handling systems and hydraulic turbine components. Hydraulic equipments and machinery like turbines, pumps, valves, etc. are usually subjected to slurry erosion. Slurry erosion of hydraulic turbines is most severe due to high mud content in rivers, particularly in monsoon season. In India, the requirement of electricity is in peak and all power producing unit wants to proficiently decrease the difference between the demand and supply. Due to slurry effect, several turbine components (guide vanes, runner, spur needle, labyrinth seal, nozzle etc.) get eroded. This leads to decrease in the turbine performance and eventually to the breakdown of the entire system. The cost concerned with installation and manufacturing of latest parts and financial losses due to breakdown of the plant are enormous, which are directly a loss to the society. Along with this, several functional parameters, such as impact angle, velocity, slurry concentration and particle properties (size, shape and hardness), material selected for various components is also of importance.

Therefore, understanding the wear mechanism in order to resolve the above problem seems to be very important. Hence, erosion studies of the developed cobalt based clad was carried out through the experimental design technique. The experiments have focused on sand slurry concentration profiles, velocity profiles and impact angle effect. The results of these parameters are very important in order to understand the erosion rate or removal of material.

### 3.1 Slurry Erosive Wear Studies

In today's world slurry handling equipments are facing lot of engineering problems which is namely erosion. Slurry erosion plays a very important role in the design and operation of slurry transportation systems. The slurry erosive wear study is mainly dependent on the effect of particle feed rate, impingement angle, velocity, properties of the particle and the substrate (size, shape, hardness etc.). Particles must be harder than the substrate for the occurrence of erosion and sharp edge abrasive particle makes more mass loss than spherical shape particle. The available literature shows that mass

loss depends on the material, its testing and environmental conditions[6-9]. To prevent the damage effects of slurry erosion, several surface modification methods are used. These methods provide economical solution to deal with such degradation. Among these methods, surface modification through microwave energy has attracted substantial consideration worldwide due to its versatile nature. Therefore, in the present work, efforts are made to realize the impact of slurry parameters on cobalt based clad developed through microwave energy.

The developed clad samples (25×65×6 $mm^3$) were attached to each spindle and dipped completely in the slurry pot. Silica sand particles and distilled water in 1:1 ratio was used to prepare slurry. Finally, slurry erosive wear studies were carried out under three parameters, speed (S), time (T) and impact angle (A), along with their variations at three levels. These experiments were designed based on the standard Taguchi orthogonal array (OA) L27. The obtained experimental results are tabulated in

Table1.

**Table 1: Experimental Results of Cobalt Based Clad as Per Taguchi Design ($L_{27}$)**

| S. No | Speed, S (rpm) | Time, T (min) | Angle, A (deg) | Wear (g) |
|---|---|---|---|---|
| 01 | 1000 | 60 | 15 | 0.01865 |
| 02 | 1000 | 60 | 30 | 0.01639 |
| 03 | 1000 | 60 | 45 | 0.01203 |
| 04 | 1000 | 120 | 15 | 0.02455 |
| 05 | 1000 | 120 | 30 | 0.02036 |
| 06 | 1000 | 120 | 45 | 0.01451 |
| 07 | 1000 | 180 | 15 | 0.02866 |
| 08 | 1000 | 180 | 30 | 0.02133 |
| 09 | 1000 | 180 | 45 | 0.01693 |
| 10 | 1250 | 60 | 15 | 0.03078 |
| 11 | 1250 | 60 | 30 | 0.01908 |
| 12 | 1250 | 60 | 45 | 0.01696 |
| 13 | 1250 | 120 | 15 | 0.03370 |
| 14 | 1250 | 120 | 30 | 0.02408 |
| 15 | 1250 | 120 | 45 | 0.01920 |
| 16 | 1250 | 180 | 15 | 0.03326 |
| 17 | 1250 | 180 | 30 | 0.02700 |
| 18 | 1250 | 180 | 45 | 0.02304 |
| 19 | 1500 | 60 | 15 | 0.03099 |
| 20 | 1500 | 60 | 30 | 0.02333 |
| 21 | 1500 | 60 | 45 | 0.01916 |
| 22 | 1500 | 120 | 15 | 0.03605 |
| 23 | 1500 | 120 | 30 | 0.02873 |
| 24 | 1500 | 120 | 45 | 0.02362 |
| 25 | 1500 | 180 | 15 | 0.04550 |
| 26 | 1500 | 180 | 30 | 0.03368 |
| 27 | 1500 | 180 | 45 | 0.03015 |

**3.2 Analysis of Regression Model**

General regression analysis efforts are made to model the correlation between two or more response variable and predictor variables by fitting a linear equation to the experimental data. A general linear regression model was developed for the experimental result. A regression equation thus produced relationship between the important terms generated from

ANOVA, namely, speed, impact angle, time and their interactions. The obtained general linear regression equation of the developed clad is mentioned as follows.

$$\text{Wear} = 0.00385197 + 1.85359e^{-005}\,\text{Speed} - 3.02735e^{-005}\text{Time} - 2.71552e^{-005}\text{Angle}$$

$$+\, 8.888e^{-008}\, S{*}T - 2.49213e^{-007}\, S{*}A - 4.66389e^{-007}\, T{*}A.$$

$$(S = 0.00190852,\ R\text{-}Sq = 95.32\%,\ R\text{-}Sq\ (adj) = 93.92\%) \quad (1)$$

Equation 1, relates the general regression equation used to establish the slurry erosive wear rate by substituting the values of the variables of developed clad. The positive sign of coefficients in the above equation represents that the erosive wear increases with an increase in the respective variables, while the negative sign of the equation 1, indicates the decrease in the erosive wear rate with an increase in the respective levels of variability. It means, as speed increases, the wear rate of the clad surface increases and as the impact angle of the target surface increases, the erosive wear rate decreases. It is also observed from the equation 1, that the interactions between the variables had a very least effect on the erosive wear rate of the developed clad surface. The normal probability plot for the response of the developed clad is shown in Fig2. The plot clearly represents the residuals fall closure to the normal probability line which inculpating that the errors are spread normally and the model is adequate. Collectively, the observed results designate the excellent ability of the regression model.

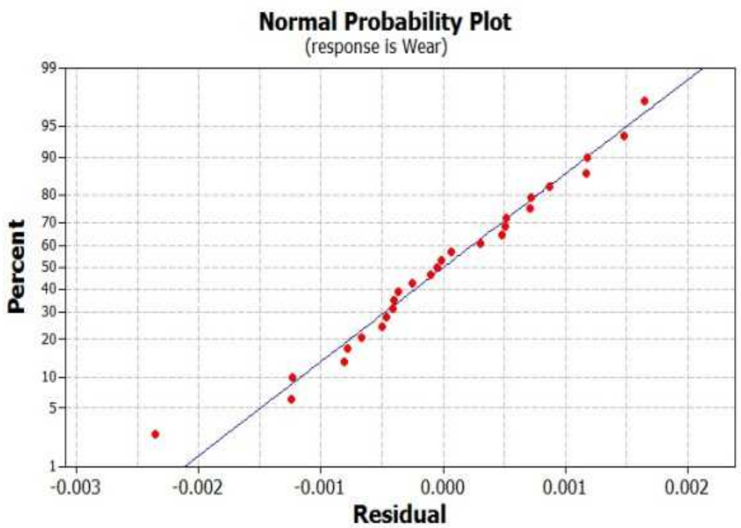


**Figure 2: Normal Probability Plot of Residuals of Developed Cobalt Based Clad**

### 3.3 Surface Response and Measure of Accuracy

Response Surface Methodology (RSM) of the statistics explores the correlations between numerous descriptive variables and one or more response variables. This method makes use of measured data of the experiments to ascertain the multivariable equations. Response Surface Methodology is productively utilized to recognize the results of erosive wear rate and the surface plots of cobalt based clad which is shown in Fig to 5. The plot (Fig3 and 4 ) exemplifies that the impact angle has the most dominating factor of erosive wear rate of the developed clad. Interactions of the other two factors such as speed (S) and time (T) had less effect on the erosive wear rate.

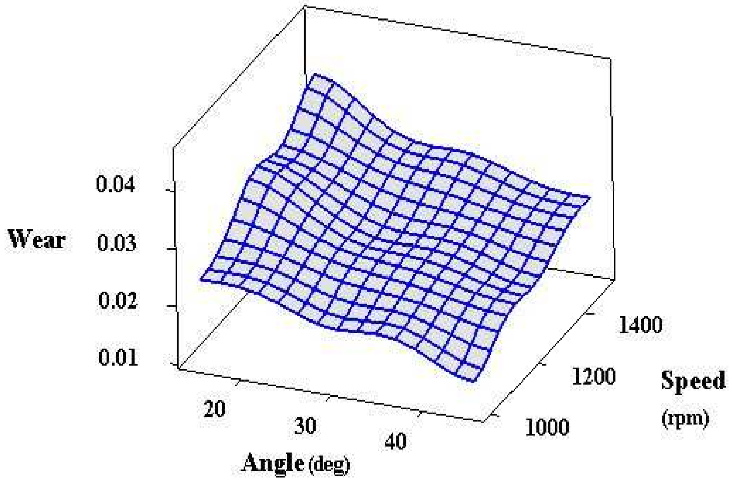


**Figure 3: Surface Plot of Angle v/s Speed of Erosive Wear Studies**

It is also observed (Fig 3.) that the interaction plots such as angle v/s time and angle v/s speed reveals the slope of impact angle is higher than the remaining two factors. Henceforth, it is very clear that the impact angle has more influence on erosive wear rate of cobalt based microwave clad. Fig 3, shows the surface plot of the erosion rate between impact angle v/s speed. Maximum erosion was observed at lower impact angle and higher rotational speed, where the minimum wear rate took place at higher impact angle with lesser speed. Hence the slope of the surface (Fig 3) is more at higher impact angle at higher speed.

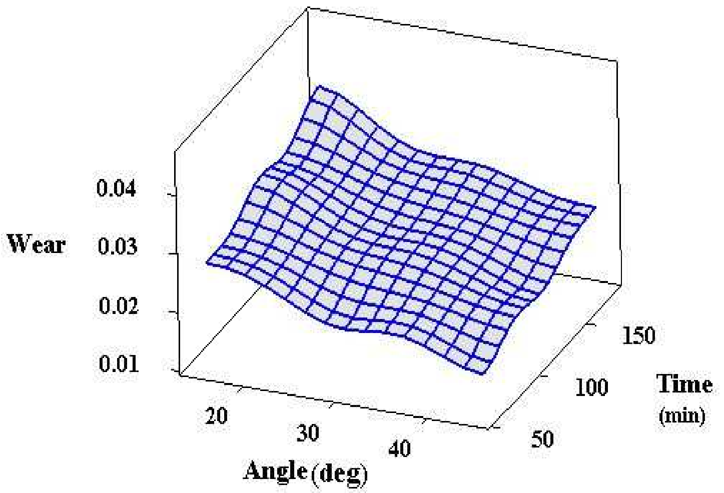


**Figure 4: Surface Plot of Angle v/s Time of Erosive Wear Studies**

Figure 4. shows that the slope of the surface is found to be more at lower impact angle at testing duration of 180 min. In the present work, the erosion rate decreased with time and finally leveled off. Hence, the slope of the plot is decreased for lesser testing time. It is observed that higher impact angle leads to reduce mass loss. It is clear from the surface plot that more mass loss has occurred at $15^0$ impact angle with 180 min of test duration. It is also observed from Fig5, that the slope of surface plot of the erosion rate is more at higher speed of rotation and minimum at lower speed of rotation. Minimum mass loss was observed at lower speed and lesser time duration, while the maximum mass loss occurred at higher speed (1500 rpm) and longer test duration (180 min).

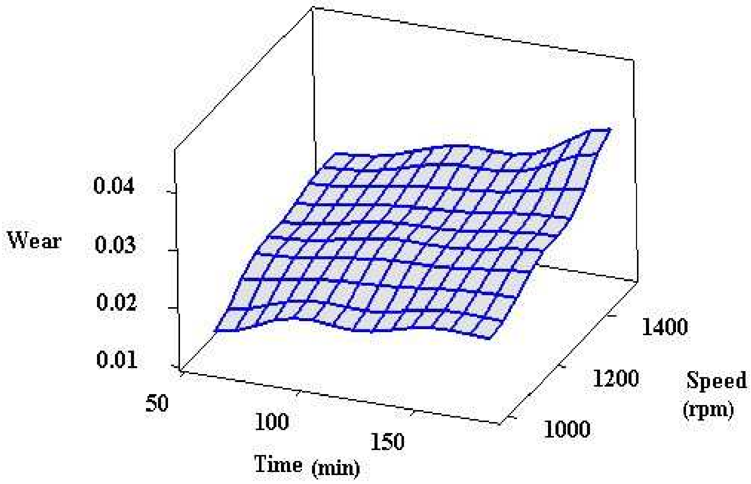


**Figure 5: Surface Plot of Time v/s Speed of Erosive Wear Studies**

## 4. CONCLUSIONS

A domestic microwave oven was used to develop cobalt based clad on the substrate (AISI-420). Wear behavior of developed clad surface was evaluated as per Taguchi orthogonal array. The obtained results are discussed as follows.

- Cobalt based clads were developed on martensitic stainless steel (AISI-420) using domestic microwave applicator.
- The developed clad structure is free from initial interfacial cracks and pores.
- Slurry erosive wear studies were carried out under three parameters, speed (S), time (T) and impact angle (A), along with their variations at three levels.
- It is observed that, as speed increases, the wear rate of the clad surface increases and as the impact angle of the target surface increases, the erosive wear rate decreases.
- It is also observed from the regression model that the interactions between the variables had a very least effect on the erosive wear rate of the developed clad surface.
- As observed from the response of surface methodology, maximum erosion was observed at lower impact angle and higher rotational speed, where the minimum wear rate took place at higher impact angle with lesser speed.

***REFERENCES***


1. *H. S. Grewal, H. S. Arora, H. Singh, A. Agrawal, and S. Mukherjee, 2014. Improving Erosion Resistance of Hydroturbine Steel Using Friction Stir Processing, J. Tribol., (pp. 41102-10), vol. 136, no. 4.*
2. *H. S. Grewal, H. S. Arora, H. Singh, A. Agrawal, 2013. Surface modification of hydroturbine steel using friction stir processing, Appl. Surf. Sci., (pp.547-555), vol. 268.*
3. *Y. P. Kathuria, (2000), Some aspects of laser surface cladding in the turbine industry," Surf. Coatings Technol., (pp.262-269), vol. 132, no. 2–3.*
4. *J. K. Lancaster, (1989), Fundamentals of wear," Tribol. Int., (pp.301-302), vol. 22, no. 4.*

5. *D. Gupta and A. K. Sharma, (2011), Development and microstructural characterization of microwave cladding on austenitic stainless steel, Surf. Coatings Technol., (pp.5147-5155), vol. 205.*
6. *T. Manisekaran, M. Kamaraj, S. M. Sharif, and S. V. Joshi, (2007), Slurry erosion studies on surface modified 13Cr-4Ni steels: Effect of angle of impingement and particle size, J. Mater. Eng. Perform., (pp.567-572), vol. 16, no. 5.*
7. *H. H. Tian and G. R. Addie,(2005), Experimental study on erosive wear of some metallic materials using Coriolis wear testing approach, Wear, (pp.458-469),vol. 258, no. 1–4 SPEC. ISS.*
8. *C. Thiruvikraman, V. Balasubramanian, and K. Sridhar,(2013), Slurry erosion behavior of HVOF sprayed WC- CrC-Ni coatings, Proc. Heat Treat. Surf. Eng., (pp. 531–540).*
9. *B. K. Prasad,(2000), Effects of alumina particle dispersion on the erosive-corrosive wear response of a zinc-based alloy under changing slurry conditions and distance, Wear,(pp.151-159), vol. 238, no. 2.*